# APPARATUS AND METHOD FOR SEALING A WELLBORE

The present invention relates to an apparatus and method for forming an annular seal between a patch and a tubular in a wellbore or between a patch and an open hole wellbore.

In the course of completing an oil and/or gas well, it is common practice to run a string of protective casing into the well bore and then to run production tubing inside the casing. The annulus between the casing and the surrounding formation is then sealed with a deposit of cement to prevent fluid from flowing through the annulus from one formation zone to another. If the casing traverses a hydrocarbon-bearing zone of the formation, the casing is perforated to create flow apertures through the casing and cement so that the formation fluids can flow into the well. Such perforations may subsequently be sealed using an expandable sealing member, preferably in the form of a radially expandable tubular metal patch lowered into the wellbore through the production tubing on a conventional patch setting tool. A patch may also be used to seal holes in the casing caused by corrosion or to reinforce corroded casing sections which have not yet become perforated. Still other applications, such as bridging the gap between sections of parted casing will also be apparent to those skilled in the art. In some completions, however, the wellbore is uncased, and an open face is established across the hydrocarbon bearing zone. A patch may also be used in such open face wellbores in order to increase the mechanical strength of the wellbore wall or to seal off an open face zone, for example, a water-producing zone. Where the patch is used to increase the mechanical strength of the wellbore wall, the patch is subsequently perforated where it traverses a hydrocarbon bearing zone of the formation. In other

completions, a sandscreen is used in open face wellbores. Suitably, the sandscreen that is run into the open face wellbore comprises one or more tubular ("patch") sections that lie across one or more non-hydrocarbon-bearing intervals of the wellbore, for example, a water-producing interval, and one or more screen sections that lie across one or more hydrocarbon-bearing intervals of the wellbore. Generally, an external casing packer is set in the annulus formed between the tubular section(s) of the sandscreen and the open face wellbore at each end of the tubular section(s). A cement slurry may also be introduced into the annulus formed between the tubular section(s) and the open face wellbore to ensure that the non-hydrocarbon-bearing interval(s), for example, water producing interval(s) is effectively sealed off. It would therefore be advantageous to eliminate the requirement for the external casing packers and for cementing the tubular section(s) of a sandscreen.

According to US 2003/0015246, perhaps the most common prior art approach to sealing perforations in a casing has been to use a patch comprising a cylindrical steel sleeve with a rubber-like gasket material bonded to the outer surface of the steel sleeve. Generally, for deployment, the patch is wrapped about an expansion device which is typically a mechanically operated expander plug and is subsequently lowered through the production tubing to the uncovered perforation. Upon reaching the perforation the patch is expanded to seal the perforation. Typically the patch is held in place in the well casing by friction. However, in many wells there are one or more restrictions in the production tubing with the minimum restriction imposing a limit on the diameter of the unexpanded patch. During expansion of the patch, the radial thickness of the wall of the cylindrical steel sleeve decreases. In order to mitigate the risk of the expanded patch collapsing under the external pressure exerted by the formation fluids, the maximum expansion ratio for a tubular metal patch is about 30%. A problem therefore arises when the minimum restriction in the production tubing is small compared with the diameter of the wellbore as it may not be possible to expand the patch to form a fluid-tight seal with the casing or the wall of an open hole wellbore without exceeding the maximum expansion ratio.

A solution to this problem has been to use a vertically corrugated metal liner (for example, as described in US 3,203,451) wherein the external cross-sectional perimeter of the corrugated liner is greater than the internal cross-sectional circumference of the

casing but the maximum external cross-sectional dimension of the corrugated liner is less than the internal diameter of the casing so the liner can be inserted into the casing. After the liner is placed at the desired location in the casing, an expander tool is run through the corrugated liner to cause it to assume a cylindrical shape inside the casing. The liner is thus left in substantially maximum compressive hoop stress. An expansion tool comprising an expanding cone, a collet head and collet spring arms is described. The arms have outwardly enlarged portions which perform the final forming action to force the corrugated liner into a substantially cylindrical shape as the cone and collet head are pulled through the corrugated tube. It is said that the expression "expanding" the liner into contact with the casing may be misleading. The expanding cone does expand the liner in the sense that it forces the outer ridges of the corrugations outwardly until they come in contact with the casing. Then the inner corrugations are, in a sense, expanded radially outwardly until they come in contact with the casing. It would therefore be evident to the person skilled in the art that the reformed liner is merely elastically reformed and is not subsequently plastically expanded to form a seal with the wellbore wall.

An apparatus and a method for expanding a liner patch, in particular, a corrugated liner patch, in a tubular to seal a hole therein is described in WO 98/214444. The apparatus comprises a body having a top portion, a bottom portion and a middle portion, the middle portion having an outer diameter greater than the top portion and an outer diameter greater than the bottom portion; a first set of fingers disposed around the top portion of said body and a second set of fingers disposed around the bottom portion of said body; the arrangement being such that, in use, said fingers can be urged radially outwardly by displacement thereof over said middle portion (collet expander). Preferably, a cone is located above said body to facilitate deformation of the liner patch. The liner patch is expanded over the cone and finally over the fingers as the apparatus is pulled all of the way through the liner patch. Again, the term expansion refers to elastically reforming the patch as opposed to plastically expanding the reformed patch.

It is an object of the present invention to provide a method and apparatus for forming an annular fluid-tight seal between at least a portion of a plastically expandable tubular patch and the wall of a wellbore (an open face wellbore or a cased/lined wellbore).

It is also an object of the present invention to provide a patch comprising a metal tube that is capable of being deformed such that in its deformed state the patch can pass through a restriction in a wellbore to the location where the patch is to be deployed. Once at the desired location in the wellbore, the patch may be elastically reformed into a substantially regular tubular shape having an outer diameter greater than the minimum restriction in the wellbore and subsequently at least a portion of the reformed tubular patch may be plastically expanded to form a fluid tight seal with the wall of the wellbore (open face wellbore, or a cased/lined wellbore) wherein the expansion ratio for the reformed patch is in the range 10 to 30%.

Thus, according to a first embodiment of the present invention there is provided an apparatus for plastically expanding a tubular patch in a wellbore comprising:
(a) an optional gripping assembly comprising at least one radially extendible gripping member for gripping the interior wall of the tubular patch and a mechanical means for radially extending the gripping member(s);
(b) a rotatable expander tool, disposable in the tubular patch, comprising a plurality of expander elements radially extendible therefrom adapted to engage with the interior wall of the tubular patch and a mechanical means for radially extending the expander elements; and
(c) at least one electric motor for, optionally, supplying motive power to the mechanical means for radially extending the gripping member(s) of the optional gripping assembly, for supplying motive power to the mechanical means for radially extending the expander elements of the expander tool, and for providing rotation to the expander tool.

According to a second embodiment of the present invention there is provided a method for sealing a hole in a tubular in a wellbore or for sealing an open hole interval (also referred to as an "open face interval") of a wellbore comprising:
(A) introducing a tubular patch system into the wellbore and locating the system adjacent a hole in the tubular or adjacent the open hole interval of the wellbore that it is desired to seal, the tubular patch system comprising a tubular patch and an apparatus for plastically expanding the tubular patch comprising (a) a gripping assembly comprising at least one radially extendible gripping member for gripping the interior wall of the tubular patch as the patch is being introduced and located at the desired location in the wellbore and a mechanical means for radially extending the gripping member(s); (b) a

rotatable expander tool, disposed in the tubular patch, comprising a plurality of expander elements radially extendible therefrom adapted to engage with the interior wall of the tubular patch and a mechanical means for radially extending the expander elements; and (c) at least one electric motor for supplying motive power to the mechanical means for radially extending the gripping member(s) of the gripping assembly and to the mechanical means for radially extending the expander elements of the expander tool, and for providing rotation to the expander tool; and
(B) actuating the expander tool to plastically expand the tubular patch to seal off the hole in the tubular or to seal off the open hole portion of the wellbore.

The apparatus for plastically expanding the tubular patch may be run into the wellbore suspended from conventional wireline (a reinforced steel cable encasing one or more electrical wires or segmented electrical conductors) which provides support for the weight of the apparatus and electrical power for actuating the components of the expansion tool. Alternatively, the apparatus may be run into the wellbore suspended from electric coiled tubing. Suitable electric coiled tubing is described in UK patent application no. GB 2359571-A which is herein incorporated by reference.

Suitably, the apparatus may comprise a single electric motor for providing motive power to the mechanical means for radially extending the gripping member(s) of the gripping assembly, for providing motive power to the mechanical means for radially extending the plurality of expander elements of the expander tool and for rotating the expander tool, typically via a drive means. Alternatively, the mechanical means for radially extending the gripping member(s), the mechanical means for radially extending the plurality of expander elements and the drive means for rotating the expander tool may be provided with dedicated electric motors. For avoidance of doubt, the mechanical means for radially extending the gripping member(s) of the gripping assembly and the mechanical means for radially extending the expander elements of the expander tool are also capable of radially retracting the gripping member(s) and expander elements respectively.

Preferably, the mechanical means for radially extending and retracting the expander elements of the expander tool is a jack mechanism or a cone displacement mechanism comprising a conical member that is moveable in a longitudinal direction with respect to the expander elements such that the expander elements are displaced

radially outwardly or inwardly over the tapering surface of the conical member. Any other suitable electrically actuated mechanical means known to the person skilled in the art for radially extending and retracting the expander elements may also be employed. Suitably, the drive means for rotating the expander tool is a rotatable shaft. Thus, the electric motor provides rotational movement to an output shaft that is connected to the expander tool to provide rotation thereto.

It is also envisaged that the expander tool may be hydraulically actuated via at least one hydraulic pump. Thus, electric power supplied to the motor may be used to operate the pump to provide pressurised fluid to the expander tool to radially extend the expander elements. For example, the pressurised fluid may be used to actuate the cone displacement mechanism. Alternatively, the pressurised fluid may be used to directly urge the expander elements radially outwards into engagement with the interior wall of the patch. In addition, a shaft extending from the hydraulic pump may provide rotational motion to the expansion tool. Typically, the apparatus of the present invention may comprise a reservoir for a hydraulic fluid disposed in a housing. Suitably, the expansion tool is arranged below the housing. Alternatively, the pressurised fluid may be filtered wellbore fluid.

During the running in operation, the interior wall of the tubular patch, preferably, a tubular metal patch, is gripped by the least one radially extendible gripping member of the gripping assembly, for example, by at least one radially extendible "slip". Preferably, the at least one radially extendible gripping member grips the interior wall of the tubular metal patch at the upper end thereof. Suitably, the gripping member(s) comprises teeth or other gripping elements. Preferably, the apparatus is provided with a plurality of "slips", preferably 2 to 4 slips. Suitable "slips" for use with the patch would be well known to the person skilled in the art. Preferably, the mechanical means for radially extending and retracting the gripping member(s) of the gripping assembly may be a jack mechanism or a cone displacement mechanism, as described above for the expander tool. Preferably, the gripping assembly remains fixed in place in the tubular patch while the expander tool is rotated i.e. the gripping assembly does not rotate with the expander tool. It is also envisaged that the radially extendible gripping member(s) of the gripping assembly may be hydraulically actuated, as described above for the expander tool. Thus, the electric motor may drive a hydraulic

pump thereby providing pressurised fluid to the gripping assembly to radially extend the gripping member(s).

Suitably, as an alternative to holding the patch at the desired location using at least one radially extendible gripping member, an upper section of the patch may be fixed in position in the wellbore by means of a plurality of mechanical dimples, for example circular shaped dimples arranged circumferentially around the tubing at the desired location, as described in Figure 16 of US 6,223,823 which is herein incorporated by reference. Suitably, at least 3 dimples are provided. The mechanical dimples may be activated by means of internal pressure applied by the expander elements of the expander tool. Preferably, a resilient annular sealing member is provided on the external surface of the patch in the vicinity of the dimples to impart an anchoring surface against which the dimples engage thus improving the contact between the patch and the wall of the tubular (for example, the casing or liner of a wellbore) or with the open hole wellbore (open face wellbore). Thus, the gripping assembly may be omitted from the apparatus of the present invention.

Once the tubular patch system has been lowered to a level proximate a perforation or a damaged section of a tubular (for example, casing or liner) or the system lies within an open hole interval of the wellbore, at least a portion of the tubular patch is plastically expanded by rotating the expander tool and actuating the mechanical means for radially extending the expander elements such the expander elements engage with the interior wall of the patch and a portion of the patch is plastically expanded against the wall of the tubular (for example, casing or liner) or the wall of the open hole wellbore thereby forming an annular fluid-tight seal. Suitably, the expander elements of the expander tool are rollers or balls that may be radially extended or retracted via the electrically actuated mechanical means (for example, a jack mechanism or cone displacement mechanism). Preferably, the rollers have a longitudinal length of from 0.5 to 5 inches, for example 0.5 to 3 inches with the longitudinal length of the annular seal corresponding to the longitudinal length of the rollers. Where the radially extendible elements of the expander tool are balls, the annular seal has a longitudinal length of approximately half the ball diameter. The diameter of the balls and hence the longitudinal length of the annular seal is dependent upon the internal diameter of the wellbore and the external diameter of the tubular patch. For example, where a 3 inch

external diameter tubular patch is deployed in a wellbore having a 4.5 inch internal diameter casing, the balls preferably have a diameter of at least 1.5 inch, preferably, 1.5 to 3 inches, for example about 2 inches. Accordingly, the annular seal preferably has a longitudinal length of 0.75 to 1.5 inches.

Preferably, the expander tool is also provided with an electrically actuated mechanical means for moving the radially extendible expander elements of the expander tool longitudinally within the tubular patch thereby extending the annular seal. Preferably, the mechanical means is a screw mechanism. Suitably, the screw mechanism is actuated by means of a dedicated electric motor. Accordingly, the apparatus of the present invention may be used to form a seal along the entire length of the patch by gradually moving the expander tool through the patch. Alternatively, the apparatus of the present invention may be used to form a plurality of annular (ring) seals. Preferably the annular (ring) seals have a curved profile to mitigate the risk of the seal being put under stress which can lead to increased corrosion of the patch and/or the tubular.

Preferably, the annular (or ring) seal is formed by partially expanding a portion of the tubular metal patch and then longitudinally extending the expanded portion before further expanding the portion of the tubular metal patch and then further longitudinally extending the expanded portion of the tubular metal patch and repeating these steps until the portion of the patch is plastically expanded against the wall of the tubular or against the open hole and a fluid tight annular (or ring) seal is formed between the patch and the wall of the tubular or the open hole respectively. The patch is now locked in place in the tubular or in the open hole and the radially extendible expander elements may be retracted and the gripping member(s) of the gripping assembly (for example, slips) unset before moving the apparatus to a new position in the patch. The gripping member(s) of the gripping assembly (for example, slips) is then reset and a further annular (or ring) seal may be formed as described above. Preferably, the apparatus is provided with sensors for monitoring the expansion of the patch and the position of the expansion tool and gripping assembly in the wellbore thereby ensuring that the ring seals are formed at the desired location in the wellbore.

Suitably, the apparatus of the present invention may be used to deploy a patch comprising an inner metal tube and an outer resilient sealing member. Suitably, the

inner metal tube is formed from steel, preferably, carbon steel. As discussed above, the thickness of the inner metal tube will be a function of the diameter of the wellbore and the yield and tensile strength of the metal forming the tube. Preferably, the thickness of the inner metal tube is in the range 0.25 to 0.5 inches. Preferably, the outer resilient sealing member is formed from an elastomeric material that is resistant to the well environment, i.e. temperature, pressure, well fluids, and the like. Suitably, the elastomeric material is selected from rubber (for example, silicone rubber), polymers of ethylene-propylene diene monomer (EPDM), polytetrafluoroethylene, polyphenylene sulfide, and perfluoroelastomers. The outer resilient sealing member may be a sheath extending along substantially the entire length of the patch or may comprise at least one outer resilient sealing ring arranged at a location where it is desired to form an annular fluid-tight seal with the casing, liner or the wall of the open hole wellbore and having a length corresponding to the longitudinal length of the annular seal. Typically the patch may be provided with a plurality of outer resilient sealing rings thereby allowing a plurality of annular fluid-tight seals to be formed. Typically, the outer resilient sealing rings have a longitudinal length of 1 to 5 inches. Suitably, the outer resilient sealing rings are arranged at the upper and lower ends of the patch although the sealing rings may also be arranged at intervals along the patch, for example, every 0.5 to 2 feet. Typically, the thickness of the outer resilient sealing member (sheath or ring) is in the range 0.05 to 0.15 inches, for example, about 0.1 inches. Suitably, the outer resilient sealing member may be adhered to the inner metal tube. Alternatively, the inner metal tube may be a tight fit within the outer resilient annular sealing member.

Where a tubular patch is to be used to seal a hole in a tubular (or to seal off an open hole interval of the wellbore), at least one ring seal is formed above the hole (or above the open hole interval that it is desired to seal) and at least one ring seal is formed below the hole (or below the open hole interval).

Thus, according to a third embodiment of the present invention there is provided a method for sealing a hole in a tubular in a wellbore or for sealing an open hole interval of a wellbore comprising:

(A) introducing a tubular patch into the wellbore and locating the tubular patch adjacent the hole in the tubular or adjacent the open hole interval of the wellbore;

(B) (i) plastically expanding a first portion of the tubular patch above the hole in the

tubular or above the open hole interval of the wellbore into annular sealing engagement with the tubular or the open hole to form a first annular seal and (ii) plastically expanding a second portion of the tubular patch below the hole in the tubular or below the open hole interval of the wellbore into annular sealing engagement with the tubular or the open hole to form a second annular seal thereby sealing the hole in the tubular or the open hole interval of the wellbore.

Preferably, the tubular patch is located in the desired position in the wellbore and the annular seals are formed using the apparatus of the first embodiment of the present invention.

In order to strengthen the seal, a plurality of annular seals may be formed above and below the hole in the tubular or above and below the open hole interval of the wellbore. An advantage of sealing off the hole in a tubular or of sealing off an open hole interval of the wellbore by forming annular seals between the patch and the tubular or the open hole interval is that there is no requirement to plastically expand the entire patch. Suitably, the open hole interval of the wellbore may be an interval that requires hydraulic isolation, for example, a water-producing interval of the wellbore. An advantage of hydraulically isolating an open hole interval of a wellbore using the method of the third embodiment of the present invention is that this allows external casing packers and the use of cement to be eliminated.

The method of the third embodiment of the present invention may also be used in conjunction with a sandscreen comprising at least one tubular ("patch") section and at least one screen section where the sandscreen is run into a wellbore until the screen section(s) lie across a hydrocarbon-bearing interval of an open hole wellbore and the tubular section(s) lies across an interval of the open hole wellbore that it is desired to hydraulically isolate. It is envisaged that the sandscreen may be run into the wellbore supported by the gripping assembly of the apparatus of the first embodiment of the present invention. If necessary, the apparatus may be provided with a traction device to assist in placing the sandscreen at the desired location in the open hole wellbore, particularly, where the wellbore is a deviated wellbore (for example, a side track or lateral well). It is also envisaged that the sandscreen may be deployed in the wellbore using a conventional "running-in" tool before passing the apparatus of the first embodiment of the present invention through the sandscreen (supported on wireline or

electric coiled tubing) to the location where it is desired to form the annular fluid-tight seals, in which case the gripping assembly may be omitted from the apparatus. Preferably, at least one annular fluid-tight seal is formed at each end of the tubular ("patch") section(s) of the sandscreen. Preferably, a plurality of rings seals may be formed at intervals along the entire length of the tubular ("patch")section(s) of the sandscreen.

Suitably, the apparatus of the first embodiment of the present invention and the methods of the second and third embodiments of the present invention may be used to deploy a tubular metal patch in a wellbore at a location below a restriction, $D_1$, wherein the patch is capable of being deformed into an irregularly shaped tube having a maximum external cross-sectional dimension, $D_2$, and of being subsequently elastically reformed into a substantially regularly shaped tube having an external diameter, $D_3$, wherein $D_2$ is less than $D_1$ and $D_3$ is greater than $D_1$, and wherein at least a section of the reformed tube is capable of being plastically expanded to an external diameter, $D_4$, to form a fluid tight annular seal with the wall of a tubular (for example, casing or liner of a wellbore) or the wall of an open hole interval of a wellbore and wherein the expansion ratio, $[(D_4-D_3)/D_3]\times100$, is in the range 10 to 30%, preferably 20 to 30%, for example 25 to 30%.

By plastically expanded is meant that the expanded shape is maintained when an expansion pressure is no longer being applied.

Suitably, the deformed tube may be reformed into a tube of substantially uniform external diameter (i.e. a tube having a substantially circular transverse cross-section), preferably, into its original tubular shape, prior to plastically expanding at least a section of the reformed tube to form an annular fluid-tight seal with the tubular or open hole. Alternatively, a section of the deformed tube may be reformed and plastically expanded to form an annular seal prior to reforming and optionally plastically expanding the remainder of the deformed tube.

Suitably, production tubing is run into the wellbore and the patch is deployed in the wellbore through the production tubing. Typically, the production tubing has one or more restrictions therein such that the deformed patch must be capable of passing through the minimum restriction in the production tubing.

Preferably, the metal tube is deformed into a longitudinally corrugated tube of

the types well known to the person skilled in the art. It is also envisaged that the metal tube may be deformed into any other shape that is capable of passing through the restriction, $D_1$, for example, the patch may be deformed to put a groove therein, as described in US 3,489,220, which is herein incorporated by reference. Suitably, the metal tube may be deformed to a size smaller than the restriction, $D_1$, using a set of rollers located above the wellhead.

Typically, the deformed metal tube has a maximum external diameter, $D_2$, that is slightly less than the restriction, $D_1$, for example 5 to 10% less than the restriction, $D_1$. At least a portion of the reformed tubular patch is capable of being plastically expanded to form an annular fluid tight seal with the wall of the wellbore wherein the total expansion ratio for the deformed tube, $[(D_4-D_2)/D_2]x100$ is 40 to 50% with the proviso that the expansion ratio for the reformed tube, $[(D_4-D_3)/D_3]x100$, is in the range 10 to 30%, preferably 20 to 30%, for example 25 to 30%.

Suitably, the patch may be deployed in a cased wellbore, a lined wellbore or an open hole wellbore with the patch forming an annular fluid tight seal with the wall of the casing, liner or the open hole respectively. It is envisaged that a plurality of portions of the reformed patch may be plastically expanded to form a plurality of annular seals. Alternatively, the deformed tubular patch may be reformed and plastically expanded along substantially the entire length thereof.

Suitably, the patch may be from 10 to 1000 feet in length, preferably, 30 to 600 feet, more preferably 50 to 300 feet, for example, 100 to 200 feet. The patch may be formed from tubular metal sections having a length of 5 to 40 feet, preferably 20 to 30 feet. The sections of the patch may be joined together using conventional flush joints having a maximum diameter smaller than the minimum restriction in the wellbore, in which case there is no requirement to deform the joints. Alternatively, the sections of the patch may be joined together using deformable joints. Suitably, the deformable joint comprises a male connection on a first tubular metal section of the patch and a female connection on a second tubular metal section of the patch where the male and female connections are provided with interlockable complementary formations such that when the joint is deformed and subsequently reformed, the complementary formations of the male and female connections do not break apart. For example, the male and female connections may be provided with interlockable dovetailed threads. Preferably,

the deformable joint is also capable of being plastically expanded to allow the patch to be plastically expanded along its entire length. Suitable expandable joints are well known to the person skilled in the art and may be adapted to be interlockable, for example, by employing interlockable dovetailed threads.

Suitably, the elastically deformable and plastically expandable metal patch is formed from steel, for example, a low carbon steel or other suitable metal alloy. Typically, the elastically deformable and plastically expandable metal patch may be provided with an outer resilient sealing member (sheath or ring), as described above. Preferably, the elastically deformable and plastically expandable metal patch is coated with a resilient material, typically an elastomeric material, to provide an improved annular seal with the tubular (for example, casing or liner) or with the wall of the open hole interval of the wellbore upon plastic expansion of the reformed tube. Preferably, the elastomeric material is resistant to the well environment, i.e. temperature, pressure, well fluids, and the like. Suitable elastomeric materials are as described above.

As discussed above, the thickness of the wall of the metal tube decreases as it is plastically expanded. The required thickness of the wall after expansion is a function of the diameter of the wellbore and the yield and tensile strength of the metal forming the tube. In general, as the wellbore diameter increases it is necessary to increase the thickness of the wall of the plastically expanded metal tube in order for the tube to apply sufficient force to seal the hole in the tubular (for example, perforations in the casing or liner of the wellbore) or to seal the open hole wellbore. Preferably, the thickness of the wall of the plastically expanded metal tube is in the range 0.25 to 0.5 inches for a plastically expanded tube having an internal diameter of 6 to 8 inches. Typically, the thickness of the coating of resilient material is in the range 0.05 to 0.2 inches, for example, about 0.1 inch.

In yet a further embodiment of the present invention there is provided a patch that may be deployed in a wellbore using the apparatus and method of the present invention. Suitably, the patch may be deployed at a location below a restriction, $D_1$, the patch comprising a metal tube having an outer diameter small enough to pass through the restriction wherein at least one section of the metal tube is of increased wall thickness, $t_1$, compared with the wall thickness, $t_2$, of adjacent sections of the metal tube (i.e. $t_1>t_2$) and wherein the at least one section of metal tube of increased wall thickness

is capable of being plastically expanded to form an annular (or ring) seal. Preferably, the patch is capable of being deployed through production tubing. Preferably, the difference in wall thickness, $t_1$-$t_2$, corresponds to the radial distance through which the section of metal tube of increased thickness is plastically expanded to form an annular fluid-tight seal. Preferably, the section of metal tube of increased wall thickness, $t_1$, has a reduced inner diameter compared with adjacent sections of the tube of wall thickness, $t_2$. Preferably, after plastic expansion of the section of tube of increased thickness the inner diameter of the plastically expanded section of tube is substantially the same as the inner diameter of the adjacent non-plastically expanded sections of the metal tube. Preferably, prior to expansion the patch has a substantially uniform outer diameter.

The section(s) of metal tube of increased wall thickness may be plastically expanded against the metal casing or metal liner of a wellbore to form a metal to metal annular seal. It is also envisaged that the section(s) of tube of increased wall thickness may be coated with a resilient material, preferably, an elastomeric material, in order to provide an improved seal in an open hole wellbore. Suitable elastomeric materials are as described above.

Preferably, the section(s) of metal tube of increased wall thickness, $t_1$, may be provided with an annular recess or groove on the outer surface thereof having an annular resilient sealing member, for example, an O-ring located therein. Preferably, the annular resilient sealing member is formed of an elastomeric material. Suitable elastomeric materials are as described above. Expansion of the section(s) of the metal tube of increased wall thickness, $t_1$, will force the annular resilient sealing member against the metal casing or metal liner of a wellbore or against the wall of an open hole wellbore thereby forming a fluid-tight seal.

The patch of this further embodiment of the present invention is preferably plastically expanded using the apparatus of the first embodiment of the present invention. However, it is also envisaged that the patch may be deployed using any conventional expansion tool, in particular, an expansion tool having hydraulically actuated, radially expandable members, as described in US 2001/0045284, which is herein incorporated by reference.

When the apparatus of the first embodiment of the present invention is used to reform a deformed tubular patch, for example, a longitudinally corrugated tube, at least

a portion of the tube is first reformed into its original tubular shape using the expander elements of the expander tool before plastically expanding the portion of reformed tube to form an annular (or ring) seal between the patch and the casing or liner or open hole wellbore. Preferably, the deformed tubular patch is reformed along the entire length thereof. Suitably, a plurality of portions of the reformed tubular patch may be plastically expanded using the apparatus of the present invention to form a plurality of annular (or ring) seals or, alternatively, the entire tubular patch may be plastically expanded to form a seal with the wall of the casing, liner or the open hole wellbore.

In a further aspect of the present invention, the apparatus of the first embodiment of the present invention may be used to form an annular (or ring) seal between a liner string and a cased or lined interval of a wellbore such that the annular (or ring) seal acts as a liner hanger in addition to sealing the annulus between the liner and the wall of the cased or lined interval of wellbore. Thus, the ring seal must be capable of taking the weight of the liner string. Preferably, the "liner hanger" comprises a plurality of ring seals, for example, 2 to 5 annular seals. Typically, the liner string is lowered into the wellbore, supported by the radially extendible gripping member(s) of the gripping assembly, until the upper section of the liner string overlaps the lower section of the cased or lined interval of the wellbore with the expander tool located in the upper section of the liner string. The expander elements of the expander tool are then extended radially outwardly into engagement with the interior wall of the liner string and a portion of the liner string is plastically expanded against the casing or lining to form an annular fluid tight ring seal between the upper section of the liner string and the lower section of the cased or lined interval of wellbore. Where the liner string is deployed in a deviated wellbore (lateral or side track wellbore), the apparatus of the first embodiment of the present invention may be provided with a tractor for running the liner string into the deviated wellbore. It is also envisaged that a prior art means for running the liner string into a wellbore may be employed. Once the liner string is in place in the wellbore, the apparatus of the first embodiment of the present invention may run into the wellbore to form the "liner hanger". As would be evident to the person skilled in the art, the gripping assembly may be omitted from the apparatus when the liner string is run into the wellbore using a prior art "running-in" means.

The present invention will now be illustrated by reference to Figures 1 to 10.

Figure 1 is a transverse cross-sectional view illustrating a deformable tubular patch in an undeformed state 1, and deformed into a longitudinally corrugated tube 2 having a maximum outer diameter, $D_2$ less than the minimum restriction 3 in a wellbore. Figure 2 shows the patch reformed into its original tubular shape 4 and in a plastically expanded state 5. Figure 3, illustrates a deformable and plastically expandable dovetail joint 6 for joining sections of the deformable tubular metal patch.

Figure 4 is a longitudinal cross sectional view showing a tubular metal patch 10 in position in a cased wellbore 11 prior to expansion of the patch against the casing wall 12. The patch 10 is provided with a section 13 of decreased internal diameter and hence increased wall thickness. Figure 5 shows the patch after a metal to metal ring seal 14 has been formed at the location of the section of decreased internal diameter.

Figure 6 illustrates a modified patch of the type shown in Figures 4 and 5 wherein the section 13 of patch of decreased internal diameter and hence increased wall thickness is provided with an external groove 17 adapted to receive an O-ring, 15, formed from an elastomeric material. Figure 7 shows the patch in annular (or ring) sealing engagement with the walls of a wellbore 16 which may be either a cased or lined wellbore or an open hole wellbore.

Referring to Figure 8, a production tubing 20 having a restriction 21 is positioned within the casing 22 of a wellbore. A liner 23 is hung from the casing 22 via a casing hanger 24. An apparatus for deploying a tubular metal patch 25 is lowered into the wellbore through the production tubing 20 suspended from a wireline 26. The apparatus comprises a connector 27, a controller 28, a first electric motor 29 for actuating a screw mechanism (not shown) for radially extending and retracting slips 30, and an expander tool comprising a jack mechanism 31 for radially extending and retracting rollers 32, and a rotatable shaft 33 that extends from a second electric motor 34 through patch 25 to a third electric motor 35. The second electric motor 34 actuates the jack mechanism 31 and a means (not shown) for driving the rotatable shaft 33 while the third electric motor 35 actuates a screw mechanism (not shown) for moving the rollers 32 in a longitudinal direction within the patch 25. The slips 30 are shown in their radially extended position gripping the tubular metal patch 25. Once the patch 25 is in the desired location in the wellbore, the shaft 33 is rotated and the rollers 32 are gradually radially extended to plastically expand the patch until the patch forms an

annular fluid tight seal with the wall of the liner 23. At various stages during the radial extension of the rollers 32, the third electric motor 35 actuates the screw mechanism to move the rollers upwardly and downwardly within the patch 25 thereby extending the annular seal. Figure 9 shows the result of this operation with a section of the patch 25 plastically expanded to form an annular seal 36 with the wall of liner 23. Referring to Figure 10, the rollers 32 and slips 30 are retracted before moving the expansion tool to a new position in the patch and radially extending the slips 30 to grip the interior wall of the patch. The expansion tool is then actuated to plastically expand the new section of patch, as discussed above. The third electric motor 35 may be provided with a "steady" having a centraliser 37 that engages with the liner 23. This operation may be repeated until the entire lower section of the patch has been plastically expanded against the wellbore wall. As shown in Figure 11, the apparatus may then be moved upwardly through the wellbore until the expander tool is located in the upper 38 unexpanded part of the patch 25. The slips 30 are then radially extended to engage with the wall of the casing 22 and the expander tool actuated as described above to plastically expand the upper section 38 of the tubular metal patch. The rollers 32 and slips 30 may then be retracted and the apparatus removed from the wellbore by pulling the wireline leaving behind the plastically expanded patch in annular sealing engagement with the wall of the liner 23. Although the installation of the patch is described in relation to a vertical wellbore, the apparatus of the present invention may also be deployed in a deviated well, for example, a side track or lateral well. If necessary, the apparatus may be provided with a tractor to assist in moving the tubular patch through the deviated well.